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ON THE PRESSURE DEPENDENCE OF THE COSMIC RAY INTENSITY RECORDED BY THE STANDARD NEUTRON MONITOR

by Stig Lindgren

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Abstract

The pressure coefficients have been determined for some standard neutron monitors at high latitudes for the years 1957-1959 with due regard to variations of primary origin. The following coefficients were obtained: 1) for Murchison Bay and Uppsala $\bar{\alpha} = -0.710 \pm 0.006$ per cent/mb; 2) for Resolute, Churchill and Ottawa $\bar{\alpha} = -0.725 \pm 0.005$ per cent/mb; 3) for Mawson and Mt. Wellington $\bar{\alpha} = -0.736 \pm 0.004$ per cent/mb. The differences in α between the three groups of stations are certainly real to some extent. They probably reflect dissimilarities in the neutron monitors and the pressure recording devices. As a by-product it has proved that for two stations above the latitude knee, the quotient between the pressure corrected daily neutron intensities is remarkably constant in time. It can thus be used as a sensitive indicator of changes in counting rate.

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1. Introduction

The standard neutron monitor recommended for the IGY is a local neutron production detector, i.e. it detects neutrons most of which are locally produced in the pile itself. According to Simpson. Fonger and Treiman (1952) about 84 per cent of the recorded intensity consists of neutrons produced in the lead core, whereas about 13 per cent is made up of neutrons from stars created in the surrounding paraffin. The remaining 3 per cent consists of counter background and neutrons entering the pile from the outside.

The secondary cosmic radiation which is responsible for the local neutron production is principally composed of neutrons with energy > 50 MeV (Cocconi Tongiorgi, 1949). The links between these neutrons and the primary cosmic radiation are mainly nucleons. Meson links are present to some extent and mesons also constitute a small fraction of the star-producing radiation (Simpson et al. 1952).

The atmospheric effects on this secondary radiation to which the neutron monitor is sensitive are rather well known. For a fixed recording station the mass absorption effect is satisfactorily described by the relation

$$N(P_0 + \delta P) = N(P_0) \exp(\alpha \, \delta P) \tag{1}$$

where δP is the difference between the barometric pressure at the time of recording and the mean station pressure P_0, $N(P)$ is the intensity recorded at the pressure P and α is a negative constant (the pressure coefficient). The value of α is about -0.7 per cent/mb. Relation (1) is often written in the form

$$N(x_0 + \delta x) = N(x_0) \exp(- \delta x/L) \tag{2}$$

where δx is the difference between the actual atmospheric depth and the mean atmospheric depth x_0 of the recording station and L is a positive constant (the attenuation length or the absorption mean free path).

The presence of meson links between the primary radiation and the locally produced neutrons makes the recorded intensity dependent on the atmospheric temperature conditions. This temperature effect has been estimated theoretically by Simpson et al. (1952) and by Dorman (1957). The experimentally determined temperature coefficients are not significantly different from zero (Simpson et al. 1952).

The present paper contains a survey of some investigations on the mass absorption effect. Some determinations of the pressure coefficient by the author are presented. It is claimed that the magnitude of the pressure coefficient to some extent must be considered a property of the recording apparatus.

2. A review of some investigations on the mass absorption effect

Cocconi Tongiorgi (1949) found the barometric coefficient $\alpha=(-0.84 \pm 0.05)$ per cent/mb for a paraffin-lead pile. For a similar detector Adams and Braddick (1951) obtained $\alpha=(-0.77 \pm 0.02)$ per cent/mb. From measurements with a bare graphite pile and a graphite pile with 15 cm lead they concluded that neutrons created in the atmosphere have the same pressure dependence as neutrons locally produced in lead. The same conclusions were drawn by Cocconi Tongiorgi from her experiments.

From measurements with counters surrounded by paraffin Simpson (1951) found that α increases rapidly with geomagnetic latitude at atmospheric depths between 200 and 600 g/cm^2. Simpson, Fonger and Treiman (1952) pointed out that variations in the primary radiation should be considered in determinations of α from time series. They calculated α for the Climax neutron monitor using pressure and temperature corrected data from an ionization chamber at Freiburg as a measure of the non-atmospheric variations. They obtained $\alpha=(-0.72 \pm 0.05)$ per cent/mb.

Simpson and Fagot (1953) presented measurements made with a graphite-lead pile at $\lambda = 0^{\circ}$, $\lambda = 41^{\circ}$ and $\lambda = 52^{\circ}$ at atmospheric depths between 175 and 750 g/cm^2. They concluded that independent of latitude L tends to 140 g/cm^2 at an atmospheric depth of about 700 g/cm^2. The corresponding value of α is -0.73 per cent/mb.

For the neutron monitors at Mt. Washington (1917 m above sea level) and Durham Lockwood and Yingst (1956) obtained $\alpha=(-0.73 \pm 0.01)$ per cent/mb.

Mathews (1958) presented a new method to eliminate the primary variations in the determinations of α without introducing data from more than one recorder. From some determinations for the Ottawa neutron monitor he obtained $\alpha= -0.72$ per cent/mb.

Mc Cracken and Johns (1959) obtained $\alpha=(-0.738 \pm 0.006)$ per cent/mb for Mawson and $\alpha=(-0.730 \pm 0.006)$ per cent/mb for Mt. Wellington (725 m above sea level) after elimination of the primary variations. A comparison between two determinations of the latitude effect, one at sea level, the other at 680 g/cm^2, led them to the conclusion that at the geomagnetic equator α is about 15 per cent smaller than at latitudes above 55°. From considerations of the height dependence of relative event amplitudes they concluded that α may decrease by as much as 3 per cent during marked intensity depressions. The pressure coefficients presented above are plotted in Fig. 1.

The third publication of neutron monitor data from the National Committee for the IGY in Tokyo presents data from 48 recording stations. A frequency diagram of the pressure coefficients used at these stations is shown in Fig. 1. More than 50 per cent of the stations use $\alpha = -0.72$ per cent/mb. According to Simpson and Fagot (1953) and Mc Cracken and Johns (1959) one would expect to find high mountain stations and low latitude stations in the lower part of the diagram.

3. Some new determinations of the pressure coefficient

We put $N(P_0 + \delta P) = N$ and $N(P_0) = N^*$ in Eq. (1) and apply it to two different stations (subscripts 1 and 2). We get

$$\ln (N_1/N_2) = \ln (N_1^*/N_2^*) + \alpha_1 \delta P_1 - \alpha_2 \delta P_2 \qquad (3)$$

If the differences in altitude and geomagnetic latitude are not very large, it seems reasonable to assume that $\ln(N_1^*/N_2^*)$ is a constant, C. By means of Eq. (3) we can now determine α_1 if α_2 is known and vice versa. If neither of them is accurately known, we can put $\alpha_1 = \alpha_2 = \alpha$:

$$\ln(N_1/N_2) = C + \alpha(\delta P_1 - \delta P_2) \qquad (4)$$

This equation is suitable for determinations of α without disturbing effects of primary variations. Stations above the latitude knee should be preferred as C is assumed to be a constant, and large variations in $\delta P_1 - \delta P_2$ are of course advantageous.

In the present paper the following pairs of stations have been treated:

1) Murchison Bay - Uppsala (Sweden)
2) Resolute - Churchill (Canada)
3) Churchill - Ottawa (Canada)
4) Mawson - Mt. Wellington (Australia)

They are all sea level stations except Mt. Wellington which is situated 725 m above sea level. It is clear from Fig. 2 that all the stations are located north of $\lambda = 50^\circ$ or south of $\lambda = -50^\circ$. The geomagnetic latitudes are those calculated by Cogger (1960) according to Quenby and Webber (1959).

Table I contains specifications of the periods analysed and the results, Daily means of N and P have been used throughout the calculations.

It is evident from Fig. 3 A that the pressure coefficients obtained for the Canadian stations ($\bar{\alpha} = -0.725 \pm 0.005$ per cent/mb) are in good agreement with the coefficients found by Mathews for Ottawa. The coefficients calculated for the Australian stations ($\bar{\alpha} = -0.736 \pm 0.004$ per cent/mb) also agree very well with those determined by Mc Cracken and Johns.

The Swedish stations yield values of α that are considerably smaller ($\bar{\alpha} = -0.710 \pm 0.006$ per cent/mb). However, they must be considered rather reliable as they are calculated for periods with remarkably large variations in the pressure variable $\delta P_1 - \delta P_2$. The mean value of the standard deviation of $\delta P_1 - \delta P_2$ is > 20 mb for the six periods treated.

To test the assumption $\alpha_1 = \alpha_2 = \alpha$ for the Swedish stations individual pressure coefficients have been calculated by means of Eq. (3). The periods listed in Table I were used even in this case, although they were not chosen to give maximum variations in either δP_1 or δP_2 but in the difference. In the

determination of α for Murchison Bay, $\alpha = -0.71$ per cent/mb was used for Uppsala and vice versa. The final result was $\bar{\alpha} = (-0.713 \pm 0.007)$ per cent/mb for Murchison Bay and $\bar{\alpha} = (-0.707 \pm 0.008)$ per cent/mb for Uppsala. The individual coefficients are plotted in Fig. 3 B.

The two mean values differ by 0.006 per cent/mb. About the same difference (0.008 per cent/mb) was found between Mawson and Mt. Wellington by Mc Cracken and Johns. These differences, existing <u>within</u> the Swedish and Australian groups of stations, are only about one third of the difference existing <u>between</u> the groups.

Table I. Pressure coefficients calculated according to Eq. (4)

Middle of period	Number of days	$\sigma_{\delta P_1 - \delta P_2}$ mb	α per cent/mb
Murchison Bay-Uppsala			
September 21, 1957	30	17.2	705 ± 5
November 22, 1957	49	19.4	707 ± 3
January 22, 1958	38	20.0	720 ± 3
December 11, 1958	40	16.9	705 ± 4
January 21, 1959	31	26.0	715 ± 3
February 26, 1959	23	22.3	708 ± 4
		20.3	710 ± 6
Resolute-Churchill			
October 3, 1957	28	9.0	729 ± 11
February 20, 1958	51	9.0	721 ± 9
November 11, 1958	65	9.7	729 ± 7
		9.2	726 ± 4
Churchill-Ottawa			
November 7, 1957	32	11.6	724 ± 8
February 2, 1958	48	15.5	730 ± 5
January 10, 1959	45	16.9	719 ± 4
		14.7	724 ± 5
Mawson-Mt. Wellington			
November 11, 1957	96	12.3	736 ± 5
July 6, 1958	67	12.4	740 ± 6
May 12, 1959	39	14.7	731 ± 5
		13.1	736 ± 4

4. Discussion

It seems improbable that the difference in α between e.g. the Swedish and Australian stations should be accidental as the highest value obtained for the former group is 0.01 per cent/mb lower than the lowest value obtained for the latter. The difference cannot be a latitude effect as such an effect would manifest itself in larger pressure coefficients for the Swedish pair of stations (Sec. 2).

The differences in α within the Swedish and Australian groups are not significantly different from zero. However, it should be pointed out that the larger values have been obtained for the stations closer to the poles which might be interpreted as a latitude effect.

Lockwood and Calawa (1957) have shown how large errors may be introduced in determinations of α for windy stations if the dynamical part of the total pressure is neglected. The wind speed is usually higher when the pressure is low which leads to an underestimation of α. The only mountain station treated here is Mt. Wellington and the pressure coefficient obtained for that station is one of the largest.

If the differences in α found in the present material were partly due to instrumental dissimilarities, they would be expected to be larger between the groups than within the groups as the two stations constituting a pair are built and supervised by the same staff. As what would thus be expected agrees with the actual situation it is plausibel to suspect some details of the recording apparatus.

If a pressure recording instrument gives the deviations from the normal station pressure one per cent too small, it will give rise to a pressure coefficient that is 0.007 per cent/mb too large and vice versa. It is not improbable that dissimilarities with that effect exist among the pressure recording devices.

Another detail which might be responsible for unexpected discrepancies in α, is the counter background. An increase of the background with one per cent causes a decrease of α amounting to 0.007 per cent/mb.

There are no indications outside the limits of error that α should have varied during the two years covered by the present analysis.

During the calculations it has proved advantageous to plot

$$\ln (N_1 / N_2) - \alpha (\delta P_1 - \delta P_2)$$

as a function of time in order to check the performance of the neutron monitors. In the preceding section it was assumed that for the group of stations treated here this function was independent of time: $\ln(N_1^* / N_2^*) = C$. This has not been contradicted. Fig. 4 shows an example for Murchison Bay - Uppsala. In some cases it has been possible to detect changes in counting rate due to short power failures just by careful inspection of such curves. On the other hand it has not been possible to use the curves for a study of long term variations in the quotient N_1^* / N_2^* because of the difficulties to eliminate changes in counting rate e.g. due to power failures.

Up to now $\alpha = -0.737$ per cent/mb has been used for the pressure correction of the Swedish neutron monitor data. The correct value seems to be about 4 per cent smaller, at least for Uppsala. As deviations from the normal station pressure amounting to 20 mb are usual at Uppsala and Murchison Bay and negative deviations of 40 mb occur in connection with strong depressions it is evident that considerable errors have been introduced.

However, the amplitudes of the first and second harmonics of the daily pressure variation are only of the order of 0.1 mb. For this reason no appreciable errors are inherent in the extensive studies of the diurnal and semidiurnal variations made on the basis of the Swedish neutron monitor data.

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References

Adams, N. and Braddick, H.J.J., 1951. Time and other Variations in the Intensity of Cosmic Ray Neutrons. Z. Naturforsch. 6 a, 592.

Cocconi Tongiorgi, V., 1949. On the Mechanism of Production of the Neutron Component of the Cosmic Radiation. Phys. Rev. 76, 517

Cogger, L.L., 1960. Magnetic cut-off rigidities according to the formulations of P. Rothwell and of J.J. Quenby and W.R. Webber. Multiplied type-script from ATOMIC ENERGY OF CANADA LIMITED, Chalk River Project, Research and Development.

Dorman, L.I., 1957. Cosmic Ray Variations. Translation prepared by Technical Documents Liaison Office. Wright-Patterson Air Force Base. Ohio.

Lockwood. J.A. and Yingst, H.E., 1956. Correlation of Meteorological Parameters with Cosmic Ray Neutron Intensities. Phys. Rev. 104, 1718

Lockwood, J.A. and Calawa, A.R., 1957. On the barometric pressure coefficient for cosmic-ray neutrons. Journ. Atm. Terr. Phys. 11, 23

Mathews, P.M., 1958. Atmospheric Effects on Cosmic Ray Intensity at Sea Level. Can. J. Phys. 37, 85

Mc Cracken, K.G. and Johns, D.H., 1959. The Attenuation Length of the High Energy Nucleonic Component of the Cosmic Radiation near Sea Level. Nuovo Cimento 13, 96

Quenby. J.J. and Webber, W.R.,1959. Cosmic Ray Cut-off Rigidities and the Earth's Magnetic Field. Phil.Mag. 4, 90

Simpson, J.A., 1951. Neutrons Produced in the Atmosphere by the Cosmic Radiation. Phys.Rev. 83, 1175

Simpson, J.A., Fonger, W., Treiman, S.B., 1952. Cosmic Radiation Intensity-Time Variations and Their Origin. I. Neutron Intensity Variation Method and Meteorological Factors. Phys.Rev. 90, 934

Simpson, J.A. and Fagot, W.C., 1953. Properties of the Low Energy Nucleonic Component at Large Atmospheric Depths. Phys.Rev. 90, 1068

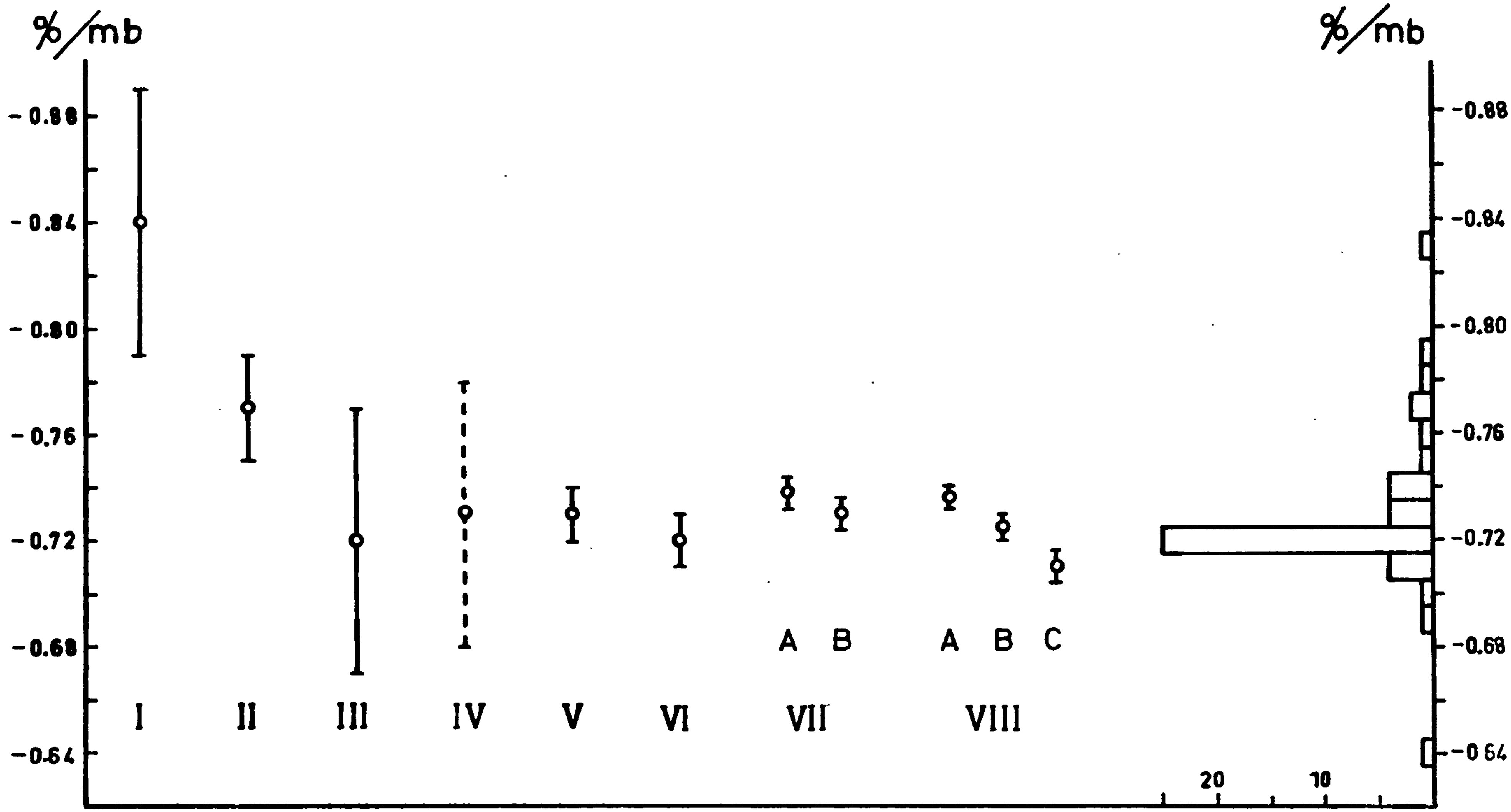

Fig. 1. Pressure coefficients determined for graphite-lead and paraffin-lead piles by
I Cocconi Tongiorgi 1949 III Simpson-Fonger-Treiman 1952 V Lockwood-Yingst 1956
II Adams-Braddick 1951 IV Simpson-Fagot 1953 VI Mathews (Ottawa) 1958
VII McCracken-Johns (A Mawson, B Mt. Wellington) 1959
VIII Lindgren (stations in A Australia, B Canada, C Sweden) 1961
To the right is a frequency diagram of the pressure coefficients used at 48 neutron monitor stations (Sec. 2).

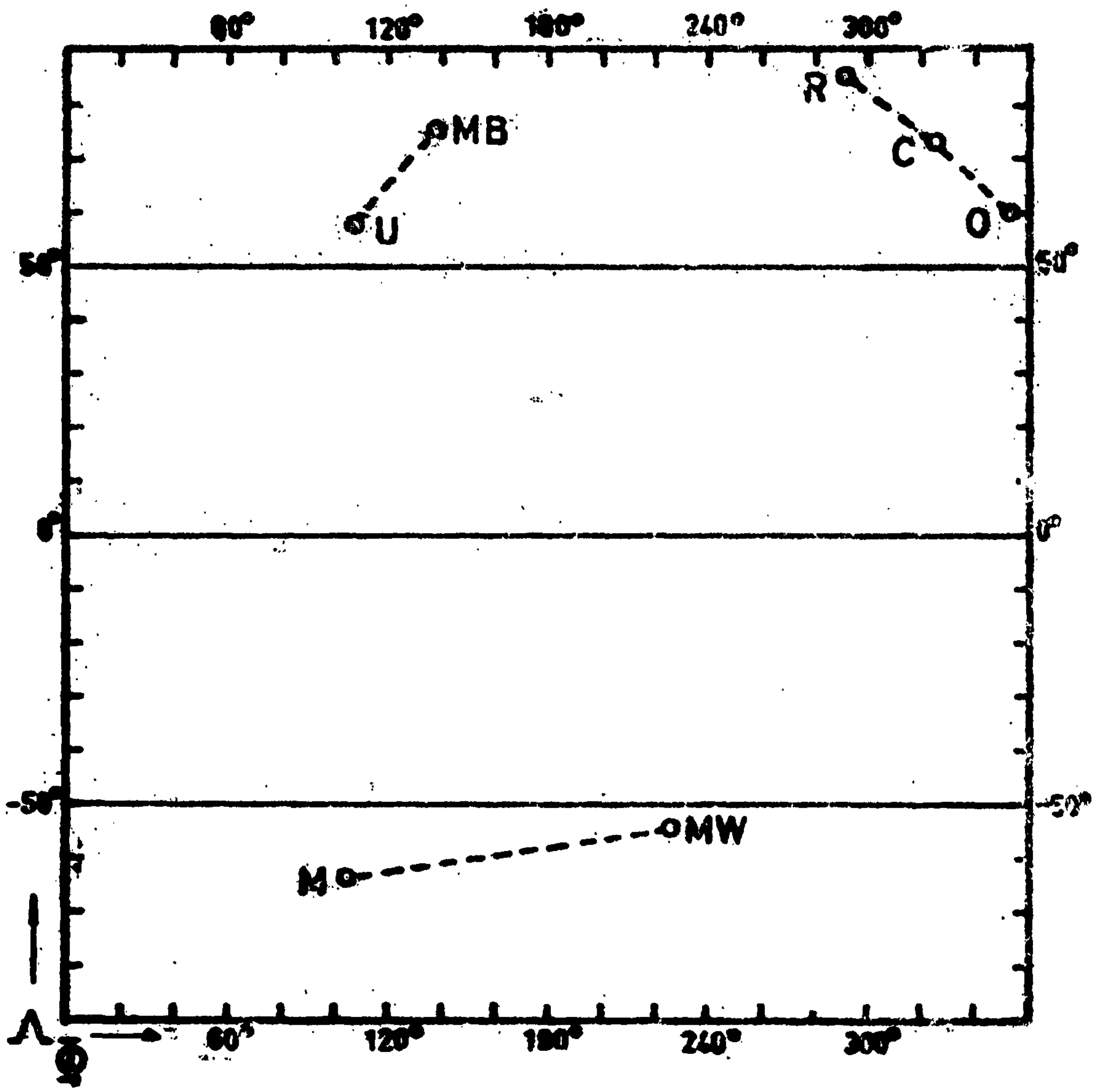

Fig. 2. Geomagnetic map with the four pairs of neutron monitor stations for which pressure coefficients are calculated according to Eq. (4)

MB = Murchison Bay
U = Uppsala
M = Mawson
MW = Mt. Wellington

R = Resolute
C = Churchill
O = Ottawa

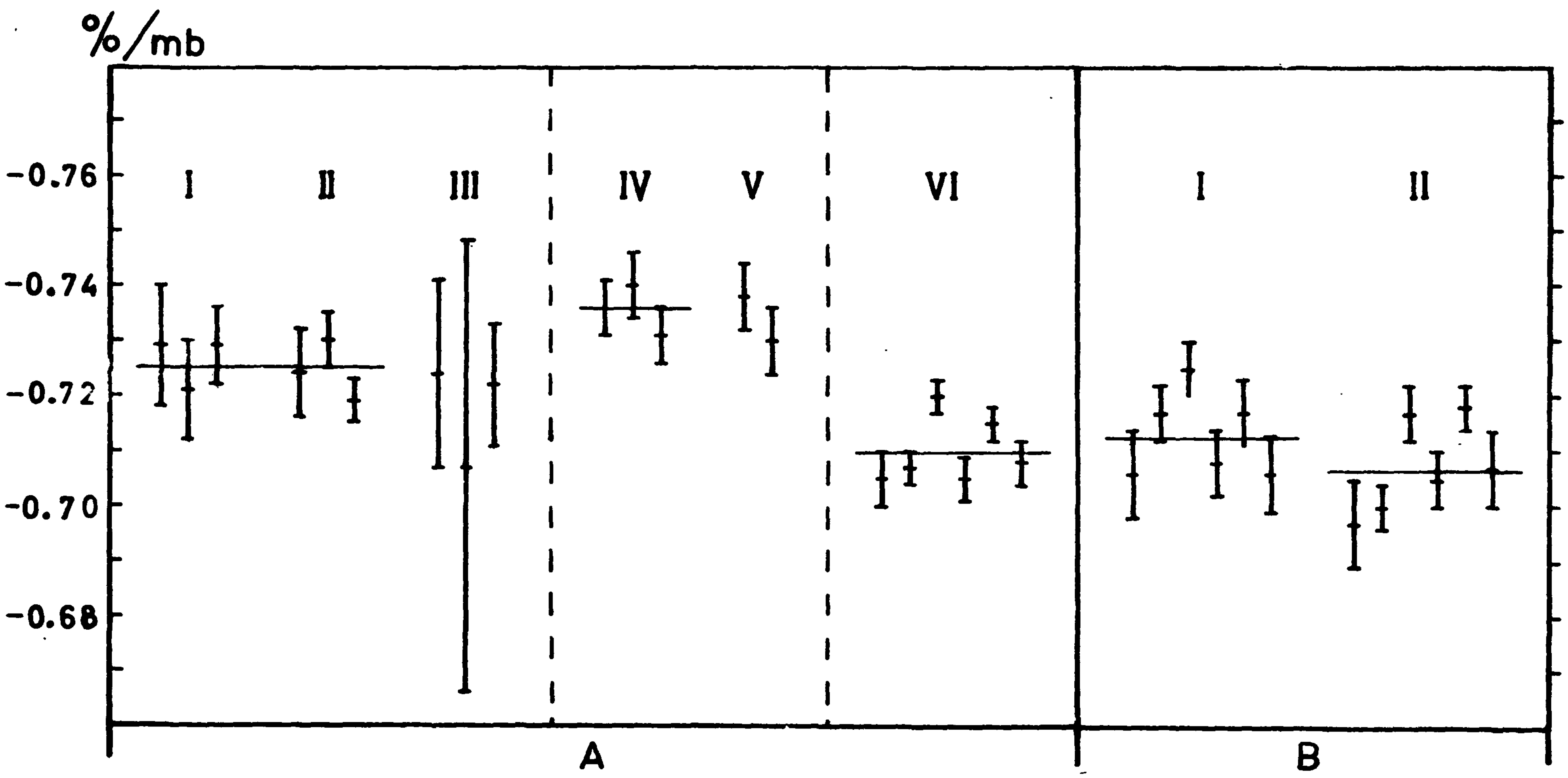

Fig. 3. A. Pressure coefficients determined for

I Resolute-Churchill, according to Eq. (4)

II Churchill-Ottawa, according to Eq. (4)

III Ottawa (Mathews 1958)

IV Mawson-Mt. Wellington, according to Eq. (4)

V Mawson and Mt. Wellington (McCracken-Johns 1959)

VI Murchison Bay-Uppsala, according to Eq. (4)

B. Pressure coefficients determined according to Eq. (3) for

I Murchison Bay

II Uppsala

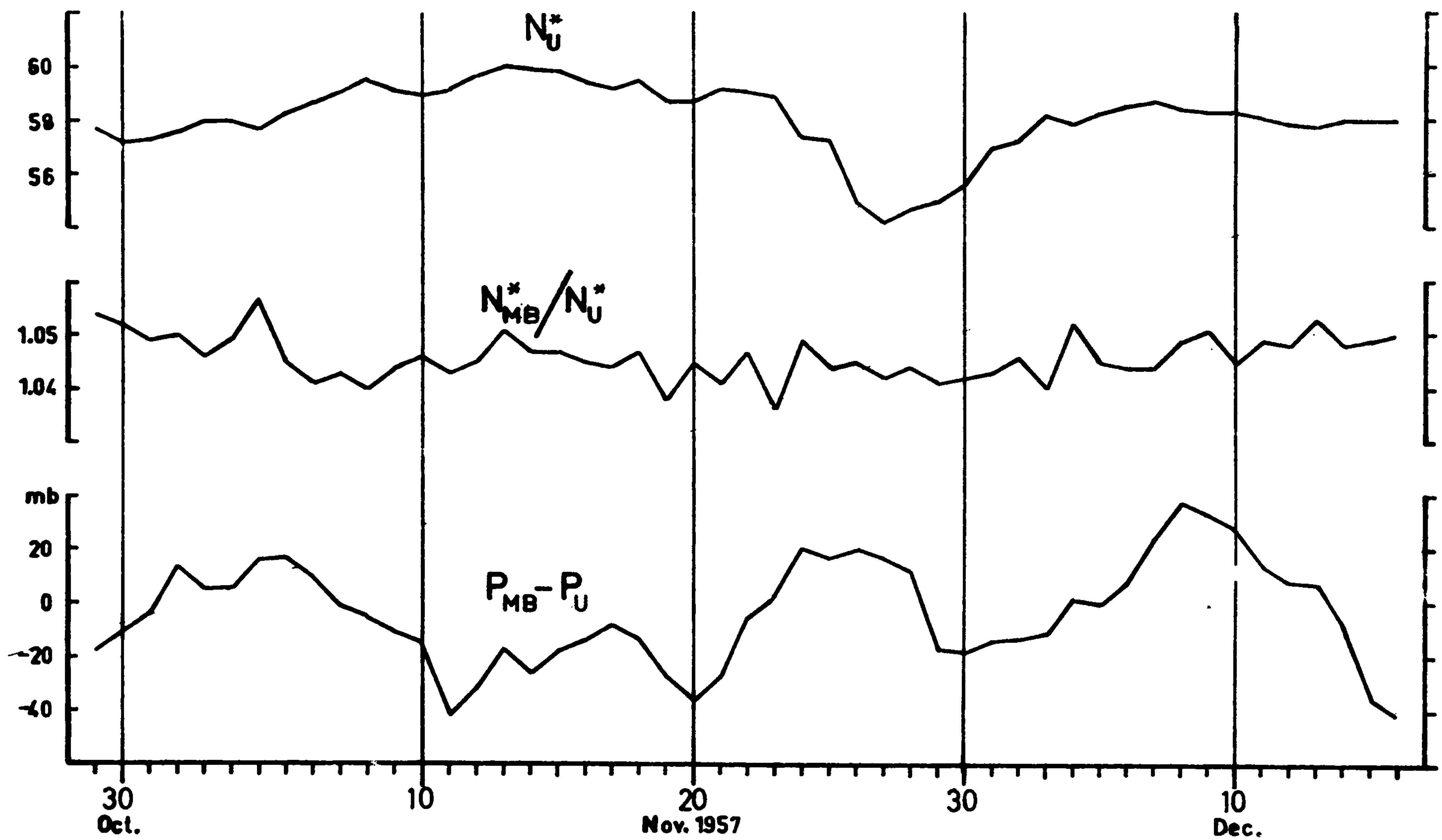

Fig. 4. N_U^* = pressure corrected intensity for the Uppsala neutron monitor.
N_{MB}^*/N_U^* = quotient between pressure corrected intensities for the neutron monitors at Murchison Bay and Uppsala.
$P_{MB} - P_U$ = pressure difference between Murchison Bay and Uppsala.
The figure illustrates the large and rapid variations in $P_{MB} - P_U$ which occur frequently. No effect of the cosmic ray decrease at the end of November is apparent in the quotient N_{MB}^*/N_U^*.

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